Realisation of compact and efficient fiber couplers in InP-membrane

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Abstract Miniaturisation and integration of optical functions on a chip are key words for optical communication at an acceptable price. Today, a large breakthrough is compromised by high coupling losses between the chip and the outside world (optical fiber). Grating couplers, when made in a high vertical index-contrast material system, can achieve high coupling efficiencies to fiber and still be very compact (10 μm). However, the InP-material system, needed for active optical functions (e.g. lasers), has a low index contrast.

In this paper, we describe the design and fabrication of compact and efficient grating couplers in InP. A high vertical index-contrast is achieved by wafer bonding. First (simple) components were fabricated, and coupling efficiencies to fiber of 30% were measured. More complex structures show theoretical efficiencies above 80%. As grating couplers fit in the philosophy of miniaturisation and integration, they are good candidates to solve the coupling problem.

Keywords **grating couplers, wafer bonding, InP-membrane**

I. Introduction

The large deviation in dimensions between an optical fiber mode and an optical waveguide mode causes high insertion losses and high packaging costs. Several solutions have been proposed to address this issue. Typically, some kind of tapered structure is used [1]. We want to explore the use of grating couplers to tackle the problem. In this approach, light is vertically coupled from fiber to waveguide, by means of a grating. This makes wafer-scale testing possible, since light can be coupled in and out everywhere on the chip, and not only at the edges of the chip. In [2], compact grating couplers in SOI (Silicon-on-Insulator), with coupling efficiencies of 25% were reported. Because of the high vertical index contrast of this material, strong gratings can be made, resulting in small coupling lengths and compact components. However, SOI is not suitable for active components (lasers, detectors, etc), which is a major drawback for application in an optical communication network.

Other materials can be used for both active and passive components. For telecom applications, InP is the material of interest. But the index contrast for this material system is rather low, inhibiting the easy transfer of existing designs in e.g. SOI.

By applying wafer bonding technology, the index contrast of the InP-based layer structure can be modified. In this paper, we report the successful fabrication of efficient grating couplers in InP, based on this technology. In a first section, we will describe the bonding principle. Afterwards, the design of bonded couplers will be covered. Finally, we will focus on fabrication issues and show some measurement results.

II. Bonding Principle

A possible definition of "bonding" is "joining of two materials". The principle is shown in Figure 1. The bonding agent BCB (a low-index polymer) is spun onto a host substrate (e.g. GaAs). The material to be bonded (consisting of an InP-substrate, an InGaAsP etch-stop layer and a thin InP membrane) is placed upside down on the host-substrate. After curing of the BCB, the substrate is removed, and also the etch- stop layer is removed. The result is a thin high index InP-layer, sandwiched between BCB and air (both of low refractive index). More details on the bonding technique can be found in [3].

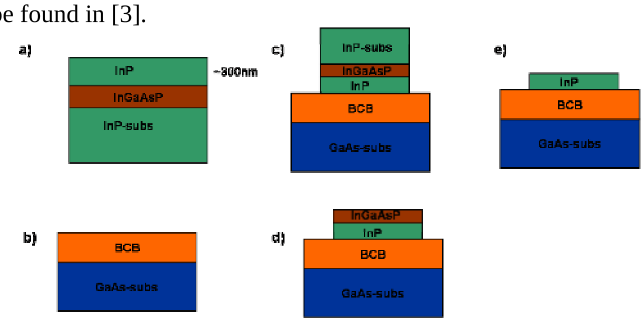

Figure 1 Bonding principle. a) layer-structure. b) host-substrate (e.g. GaAs) with BCB. c) bonding of epi-structure onto the host substrate. d) removing of the InP-substrate. e) removing of the etch-stop layer.

III. Simulations

A. Coupling to fiber by gratings

The principle of coupling by gratings is shown in Figure 2. A fiber is positioned above the grating, which performs the vertical spot size conversion. In-plane, we use a conventional spot-size converter.

The coupling efficiency of these structures can be simulated with CAMFR (Cavity Modeling Framework), a tool based on eigenmode expansion [4]. All simulations are for TE-polarisation.

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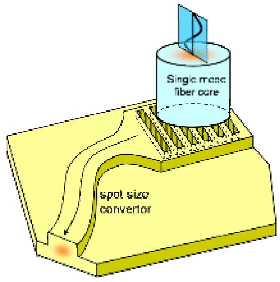

Figure 2 Fiber-to-waveguide coupling by gratings.

B. *"Bottom-grating" coupler.*

In this approach, first the gratings and waveguides are defined and afterwards, this structure is bonded onto a host substrate. Hence, the grating is at the bottom side. To avoid reflection back into the waveguide, we have to break the symmetry. Thus, we tilt the fiber by 10 degrees (near vertical coupling, in stead of vertical).

The parameters to be optimized include period, filling factor, etch depth and BCB-thickness. The optimized parameters are: period=660 nm, filling factor=0.5, etch depth=120 nm, BCB-thickness 1.18 μm. By applying an extra top layer (e.g. Al_2O_3, with optimized thickness), the coupling efficiency can be increased. The maximum coupling efficiency is 59% and the 1dB bandwith is around 50 nm. The field profile for an optimized structure is shown in Figure 3.

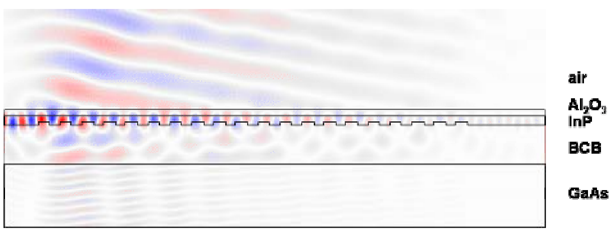

Figure 3 Field profile of a "bottom-grating coupler".

The coupling efficiency can be further increased by adding a bottom reflector (coupling efficiency of 80%), and by varying the width of the grating teeth (coupling efficiency over 90%).

IV. Fabrication

In a first fabrication run, uniform 1D-grating couplers are fabricated. On an InP-substrate, an InGaAsP etch-stop layer and a 300 nm thin InP-layer are grown. Gratings and waveguides are then defined by e-beam lithography using PMMA at the University of St. Andrews (UK). The waveguides are 10 μm wide and are bounded by 5 μm wide trenches. The pattern is then transferred into a Fox-14 (flowable oxide) hard mask by reactive ion etching (RIE). Finally, the grating is etched into the epistructure by RIE.

This structure is then bonded onto a GaAs-host substrate by means of BCB and afterwards, the InP-substrate and etch-stop layer are removed. A cross section of a fabricated structure is shown in Figure 4.

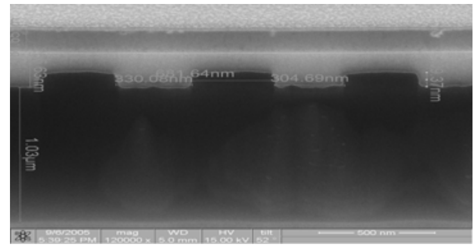

Figure 3 Cross section of a fabricated 1D grating coupler.

V. Measurements

In order to measure the performance of the coupler, a fiber, connected to a tunable laser, is positioned above the input grating at a 10 degrees angle, and another fiber, connected to a power detector, at the output grating. Assuming that input and output grating are the same, and taking losses in the measurement setup into account, the coupling efficiency can be estimated. First measurements are done without extra top layer and afterwards, a 240 nm Al_2O_3-layer is deposited.

The results are shown in the following graph. The measured coupling efficiency without Al_2O_3-layer for the 1D-grating is approximately 19% This coupling efficiency is increased to around 30 % when applying an extra top layer.

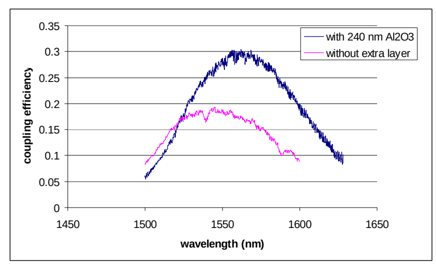

Figure 4 Coupling efficiency of a 1D-"bottom-grating coupler."

VI. Conclusions

We have presented the design and fabrication method of compact fiber-to-waveguide couplers on InP-membrane. We have demonstrated 30% coupling efficiency on first fabricated structures. This value can be further increased by e.g. adding a bottom reflector.

Acknowledgements

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